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Title: Overview of the LANL Multi-Probe Radiography Project

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Los Alamos
NATIONAL LABORATORY

Overview of the LANL Multi-Probe Radiography Project

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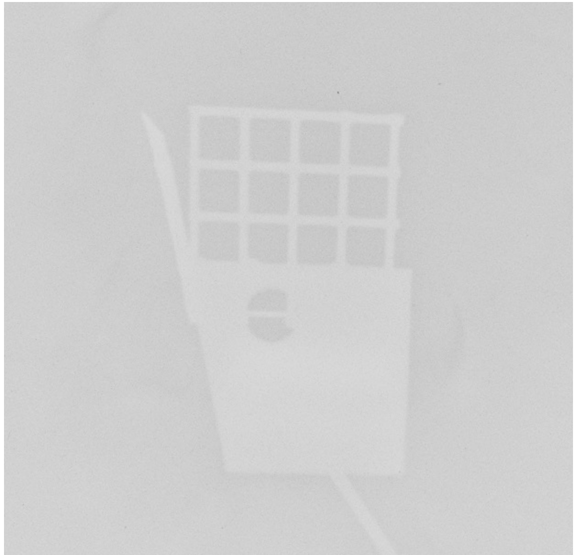
July 20, 2022

Abstract

Future radiographic facilities for the U.S. defense program will be required to provide more information as simulation codes improve in both physics' fidelity and resolution. A possible approach is to use more types of probe beams in addition to, or instead of X-rays, generated by 20-MeV electron accelerators from a small number of directions. High power short-pulse laser systems can generate beams of protons, neutrons and electrons, as well as X-rays. The cost of these systems is falling rapidly. So, it can be imagined that deploying multiple short-pulse lasers along with other, more traditional probes, will become feasible. In this project, we are following three paths to determine if such an approach will succeed for cm-scale objects. The first is an experimental one to determine if the presence of multiple short-pulse probes cause interference with each other, especially while radiographing dynamic objects. The second leg of this project is to determine if having multiple types of probes really does give more information on composition. Finally, an overall assessment of the viability of this approach will be made. Examples from recent experiments at the Omega EP laser will be presented. The initial approach to evaluating radiographs with multiple probes using the Bayesian Inference Engine (BIE) also will be given.



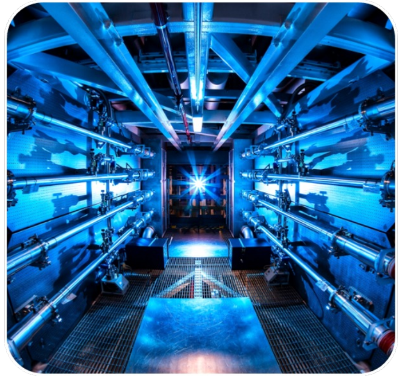
LANL depends on radiography to achieve its missions

Dual-Axis Radiographic Hydrodynamic Test (DARHT)

- Integral scale
- Scale: 10 cm
- ρR very thick

Proton Radiography (pRAD)

- Focus scale
- Scale: 1-10 cm
- ρR > 1 g/cm^2



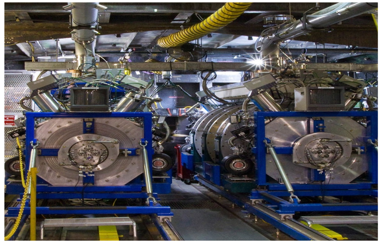
National Ignition Facility (NIF)

- Fundamental scale
- 0.1 cm
- ρR < 1 g/cm^2

LANL has invested heavily in radiography for 75 years

Phermex

DARHT 1



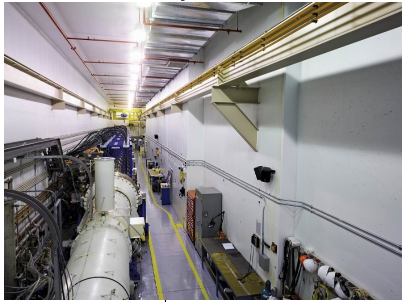
Cygnus

Future facility?

pRad

DARHT 2

Scorpius



1960s

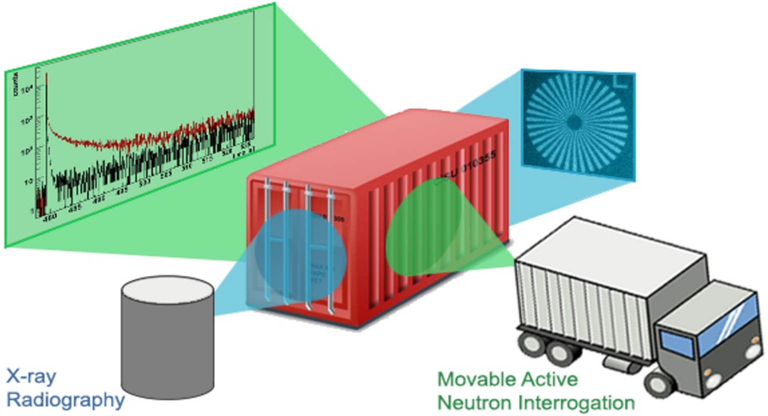
2022

2040s

Multiple probes aid material detection

- **Active Interrogation System:** Technical properties that make multi-species probing valuable as a radiographic technique for weapons experiments can advance the international nuclear security enterprise to detect special nuclear material (SNM), including shielded materials that have distinct advantages over passive (observational) techniques for which signals are generally weak

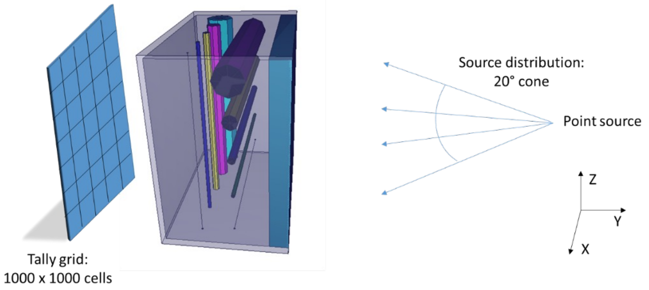
Use external neutrons to induce fission
Use external X-rays to image contents
Use external neutrons to drive nuclear (fission) reactions.

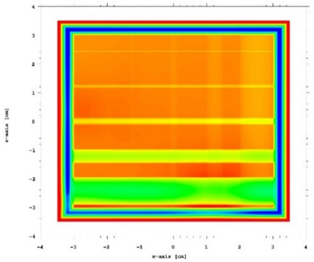


Neutron source: Requires a fast, transportable, operationally safe neutron source featuring tunable energy, and high intensity, directional neutron production

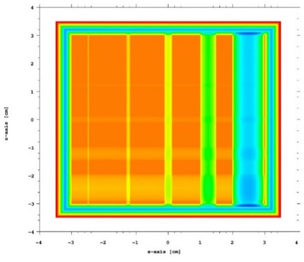
X-ray radiography: Requires a high intense, MeV energy, collimated source with a small source size for high spatial resolution

MCNP modeling illustrates the benefit of using multi-species probing





X-ray with 2.5 MeV Maxwell E distribution

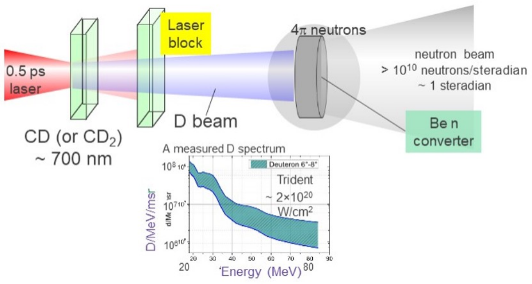


Neutron with 2.5 MeV Maxwell E distribution

Using MCNP, a notional target is interrogated with both X-ray and neutron probes.

- Two sets of 5 cylinders, orthogonal
  - Radii of 0.025, 0.05, 0.1, 0.2, and 0.4 cm.
  - One set is lead, and the other is polyethylene.
- X-ray probe returns information about high Z components
- Neutron probe returns information about low Z components.

A laser-driven deuterium (ion) beam hitting a beryllium converter produces an intense neutron beam.

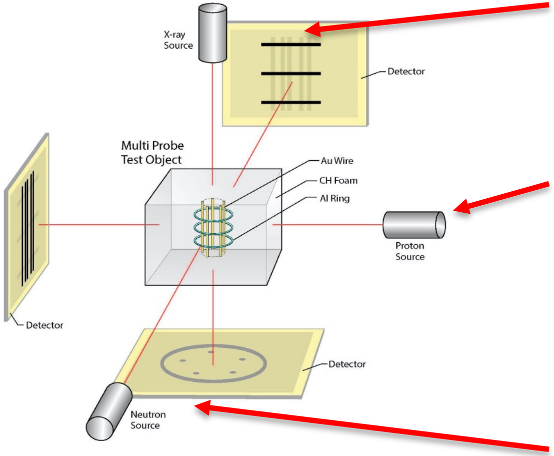


While the concept that multiple probing species provide selective sensitivity to different components of the object is no surprise, how to implement multi-species probing is not trivial nor is the analysis needed to reconstruct the object currently available.

If multiple source technologies must be supported to implement multi-species probing, its ultimate usefulness may be limited

Peta-watt-laser accelerated particles offer the promise of a single technology to produces electrons, X-rays, protons and neutrons from very compact sources, at least for fundamental and focused scale experiments.

Experiments are continuing at OMEGA-EP to characterize peta-watt-laser-driven source performance:



FY20 experiments characterized X-ray sources and demonstrated elementary dynamic radiography of a shock experiment

FY21 experiments characterized proton sources and demonstrated elementary dynamic radiography

FY22 experiments combined X-ray and proton sources to explore crosstalk and background issues, and may test multiple-species dynamic radiography In FY23 work on laser driven neutron sources is in the AD plan.

Multi-probe (MP) project has three components within the context of high-power laser-generated probes

Assessment

Determine community needs, show MP gives more information, suitability of probes

Image analysis

Demonstrate radiographs with different modalities give more information

Experiment

Field simultaneous short-pulse probes on dynamic objects

Assessment will address key questions on concept viability

- What are radiographic needs for the next 20+ years?
  - Concentrate on focused and fundamental scales
- Do multiple probes yield more information?
- Do short-pulse, laser-generated sources yield good radiographs?
- Set goals for laser sources based on radiographic needs

- These questions will be explored through a series of workshops in FY23
  - Radiographic needs
  - Laser sources
  - Accelerators
  - Detectors and image processing

Image analysis goal: Determine if multi-probe gives more information

- Use existing image analysis tool to assess if synthetic radiographs give more information
  - Use the Bayesian Inference Engine (BIE)
- Apply to dynamic data
  - With diagnostic limitations such as resolution, noise, etc.
- Suggest and evaluate alternate image analysis approaches
- Machine learning, etc.

Experiments will determine short-pulse probe characteristics

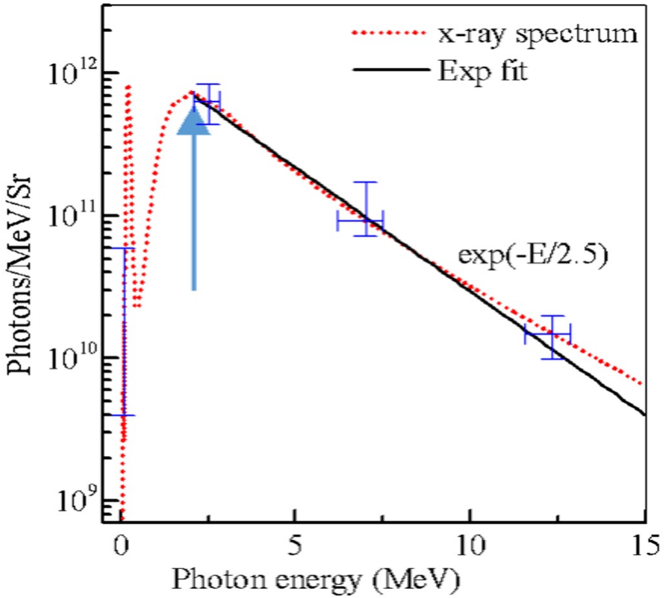
- Determine if there's any interference among different probes
- Determine if radiographs of *dynamic* objects have different issues than static objects have
- Develop "good enough" test platforms for each probe
- Omega EP gives us an opportunity to test our hypothesis
  - Short pulse/long pulse to radiograph dynamic objects
  - Two short-pulse probes
    - Get simultaneous radiographs
    - Test for interference between probes

Multi-probe experiments will establish & use different probes

- Establish x-ray, proton, and neutron platforms
  - Establish “good enough” probe platforms on Omega EP
    - Measure radiation spectrum
  - Test image quality of static objects
  - *Are these well resolved? Have low background?*

- Benchmark image quality of dynamic objects
  - *Are there any new effects during a dynamic radiograph?*
- Take simultaneous radiographs using two of these probes
  - *Is there interference or coupling between the probes?*

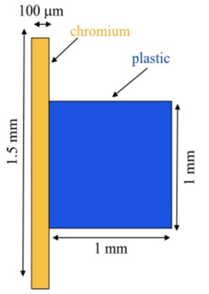
X-rays can be produced efficiently with PW lasers



- Compound (1mm Ta) target/converter performs much better than pitcher-catcher target
- Much simpler setup
- Highly reproducible
- Does not require ***high laser contrast***

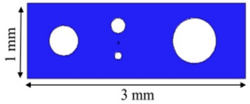
3 x10^{12} photons per shot
1J of MeV x-rays out of 80J incident laser (efficiency ~1%)

Static & dynamic proton radiography demonstrated in 2021

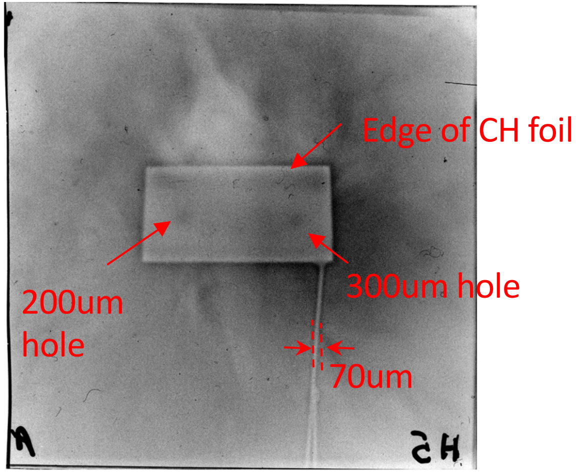


Width is 3 mm for all components (i.e. into/out of screen)

Plastic foil has 4 holes of diameter 50µm, 100µm, 200um, and 300um.

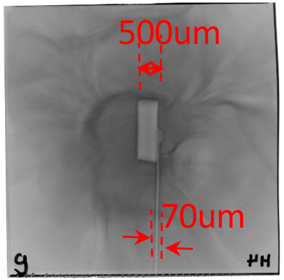


Shot 1: 158.7J

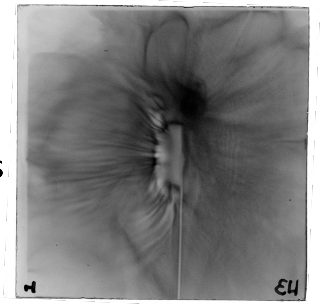


All stalks directly attached to the target bodies and were ~70 um SiB

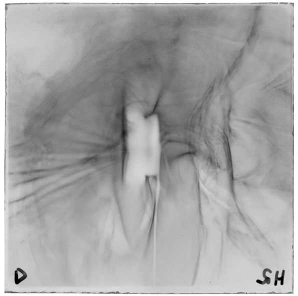
Shot 7: 312 J, UV lasers off



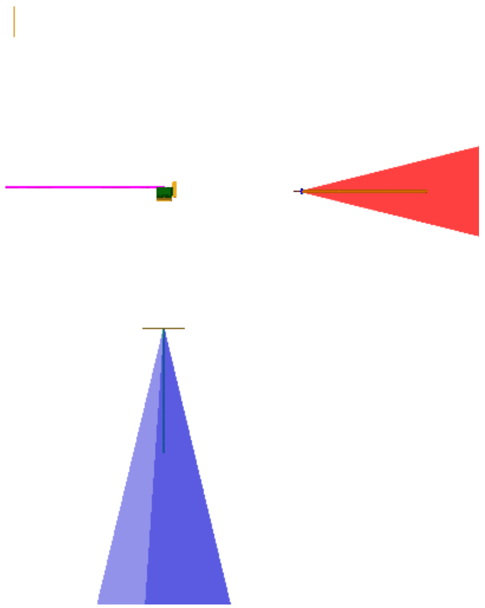
Shot 8: 312 J, 3ns



Shot 4: 310 J, 8ns

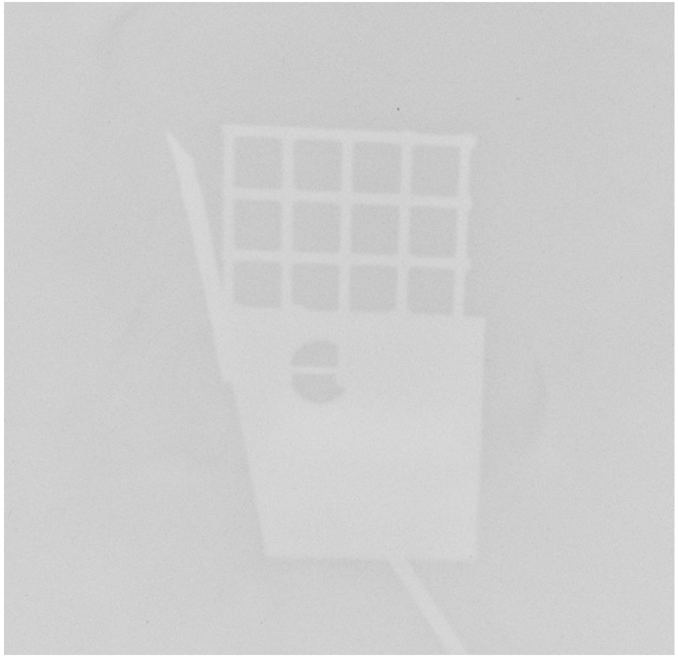


Combined X-ray and proton platforms in 2022



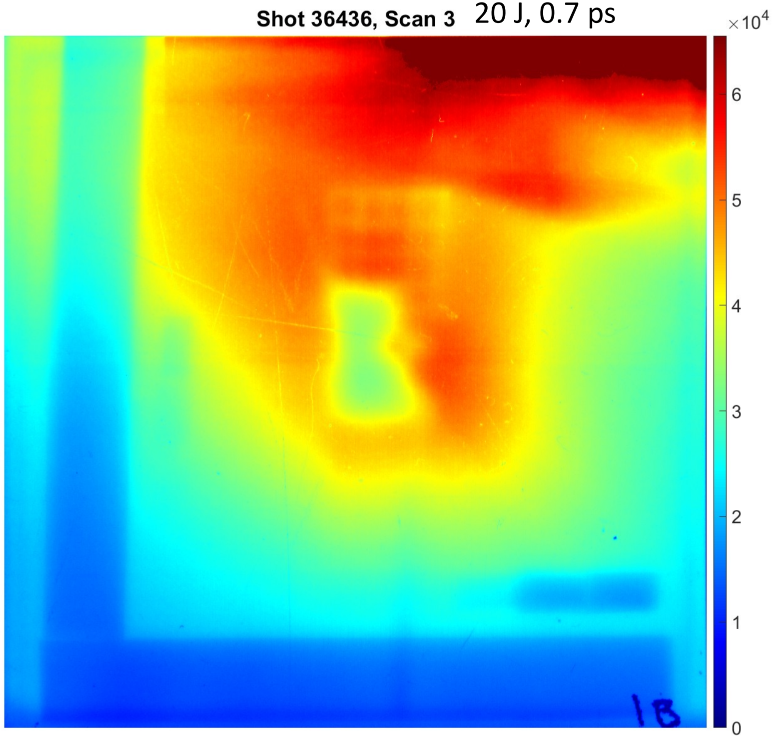
Obtained X-ray and proton radiographs establishing image quality

36442 #2; 60 J, 0.7 ps



Proton Radiograph

20 J, 0.7 ps

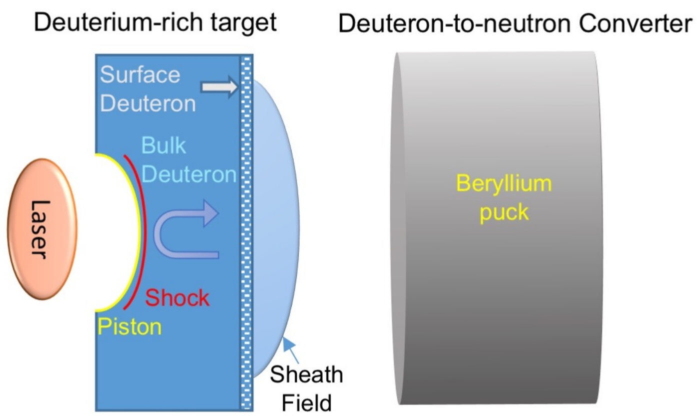


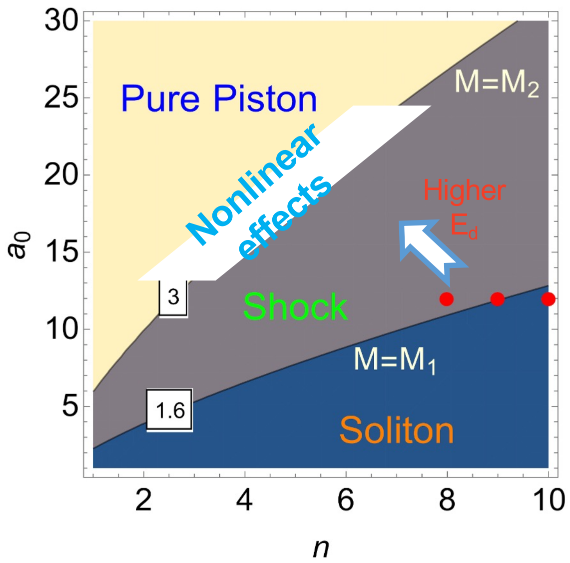
X-ray Radiograph

Identified concerns with simultaneous MP radiography

- Same platforms, 90 degrees apart
- Detected huge x-ray background coming from proton package
- Added filtering, decreased laser energy to eliminate background
- Probably moved us out of the relativistic transparency regime
  - Also softened x-ray spectrum

Future: Neutrons from bulk deuterons: Hole-boring radiation pressure acceleration or collision-less shock acceleration

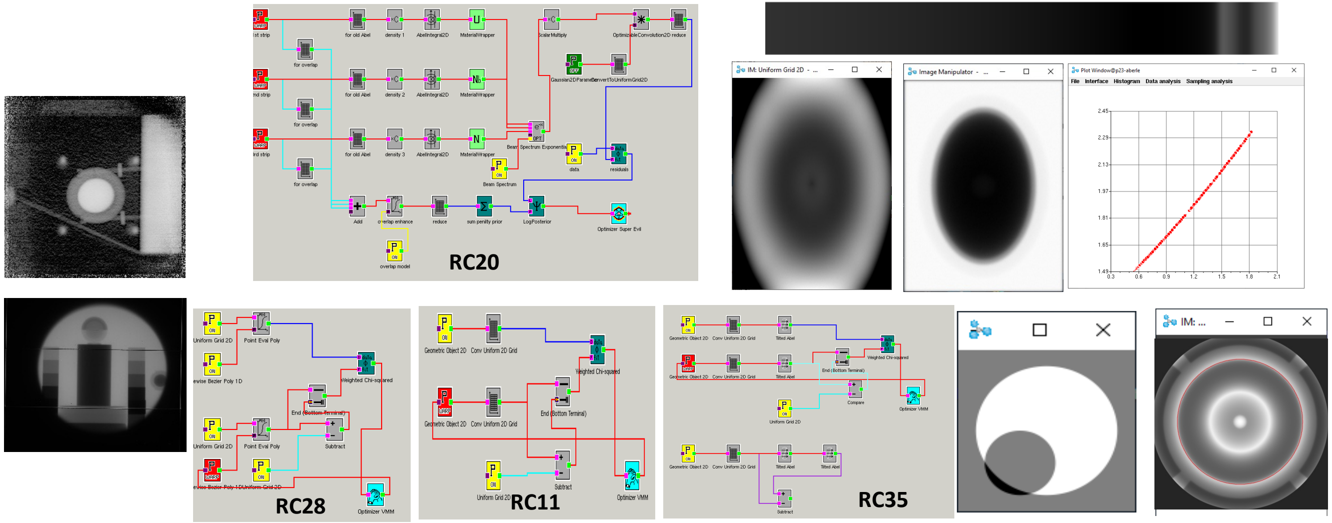




- Supersonic piston driven by laser radiation pressure sweeps through a low-density target
- Electric field from ion acoustic wave (IAW) accelerates bulk deuterons
- Nonlinear IAW can form collision-less shock with deuteron reflection at the shock front
- Additional acceleration of bulk/surface deuterons from sheath field in the gap between pitcher/catcher

Appl. Phys. Lett. 120, 024102 (2022)

Bayesian Inference Engine (BIE) uses forward modeling to determine object



- BIE is a well-developed LANL tool for analyzing radiographs
- Adding features for multiple probes

New data **Existing workflows** **Inputs/Outputs**

(forward models for synthetic images)

Jun 2022 **Sep 2022**

in collaboration with Sjue, Perry, Tompkins, Wolfe, Aberle, Chu (TBC)

Conclusions: We are demonstrating the advantages of multi-probe radiography

- Fundamental technology research for future radiography needs to happen now

- Short-pulse generated probes could be a solution
  - Need to get doses, spectrum correct
  - Source size, optimize radiography as a system
  - Need to evaluate viability

- We are assessing these prospects

Experimentally:

  - Established X-ray and proton platforms on Omega EP
  - Did first test of simultaneous X-ray and proton imaging
  - Future: neutron imaging

BACKUP SLIDES

An aside: The same technical properties that make multi-species probing valuable as a radiographic technique for weapons experiments can advance the international nuclear security enterprise

Active Interrogation systems to detect special nuclear material (SNM), including shielded materials, have distinct advantages over passive (observational) techniques for which signals are generally weak

- Use external neutrons to induce fission
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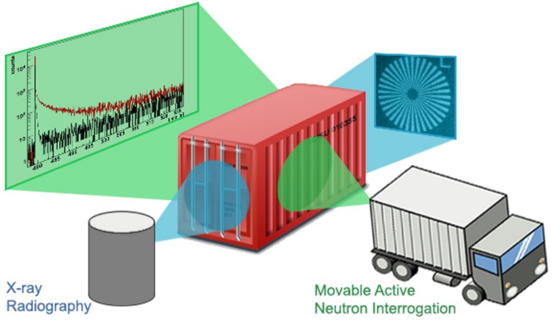

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